ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Earth and Planetary Science 3 (2011) 11 – 16

Procedia
Earth and Planetary Science

2011 Xi′an International Conference on Fine Geological Exploration and Groundwater & Gas Hazards Control in Coal Mines

The Use of Bench-scale Treatability Studies in the Design of Engineered Wetlands for the Remediation of Acid Mine Drainage (AMD) and Leachate in the Vicinity of Coal MinesA Case Study in Ohio, United States

Gary I. Lagos*, M.Sc., P. Geo.

Conestoga-Rovers & Associates, 651 Colby Drive, Waterloo, Ontario N2V 1C2, Canada

Abstract

Engineered wetland systems are a passive treatment technology which are versatile, environmentally-friendly, and cost-effective for the remediation of acid mine drainage (AMD) and leachate.

Experience derived from a site in Ohio, United States, showed that the preliminary design of an engineered wetland system downstream of a former coal mine/landfill could be significantly improved by the performance of bench-scale treatability studies. Results from the bench-scale treatability study showed that in order to achieve significant reductions of iron in the water discharging to the surface water bodies. The pH of the water would have to be increased to 8 by the addition of limestone.

Keywords: *engineered wetland systems; acid mine drainage (AMD); bench-scale treatability study.*

1.0 Introduction

Engineered wetland systems are a passive treatment technology. Key features of this wastewater technology are that its removal methods mimic rather than overcome natural processes and its cost of operation and maintenance is significantly lower than for technologies which employ active treatment

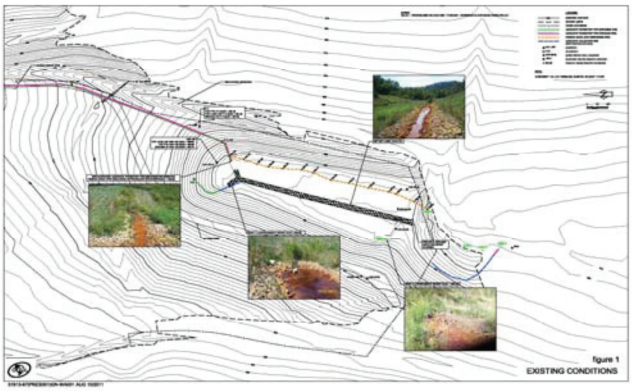
* *Corresponding author. Tel.:+1-519- 884-0510; Fax: +1-519-725-1395*
E-mail address: glagos@CRAWorld.com.

doi:10.1016/j.proeps.2011.09.059

processes (USEPA, 1993; Smith, 1997). In addition, unlike most active treatment technologies, engineered wetlands have a high degree of versatility. These systems are generally comprised of a series of typically lined ponds or treatment cells filled with sand or gravel. Plants such as cattails, reeds, and other open water, transition and upland plants are planted in the system and assist in the removal of contaminants from the waste stream (Kleinmann et al., 1983; Norton, 1992).

Within the wetland system, organic contaminants are captured and subsequently degraded by physical and chemical processes with support from the wetland plants and microbial populations. Metal contaminants can be adsorbed onto the wetland soils or converted to insoluble salts. Wetland ponds also store runoff and rainfall, reduce flooding and soil erosion, and purify water by filtering wastes, sediments, and toxic compounds.

Generally metals are removed in the aerobic zones by precipitation, chelation, and exchange reactions. Neutralization is mainly achieved in anaerobic zones by the activity of sulfate-reducing bacteria and the sincrease in alkalinity associated with the addition of limestone beds/drains (Brodie et al., 1992).



2.0 Basis for the Preliminary Design

Both surface water and groundwater impacted by acid mine drainage (AMD) and leachate at the Site have high concentrations of iron (199 to 730 milligrams per liter [mg/L]) and low pH (5.2 to 6.1). The impacted water eventually discharges to Kings Run and Little McMahon Creek causing deterioration of water in these surface water courses.

The proposed treatment system to minimize impact to the downstream surface water courses consists of a surface flow engineered treatment wetland to be located downgradient and downstream of groundwater and surface water flow in an area known as the Southern Toe area of the Site. The size and layout of the proposed wetland was developed to best utilize the available space within the existing valley of the Southern Toe area and continue gravity flow to the Principal Spillway.

The Southern Toe area is a low lying area approximately 2 acres in size with typical side slopes of 3 horizontal to 1 vertical and 20 to 25 feet in height. The Southern Toe area is vegetated with grasses and some bull rushes/cat tails (previously planted) in wetter areas. The Site landfill leachate collection and Kings Run French drain systems as well as separately collected leachate seeps discharge to the Southern Toe. A Principal Spillway consisting of riprap in a shallow channel collects leachate and discharges it to Kings Run through a spillway at the south end of the Southern Toe. All these features and the degree of deterioration in surface water are shown on Figure 1.

The preliminary wetland design included two treatment cells separated by a berm. These treatment cells (Cells 1 and 2) would be located south of the leachate transport pipe, King's Run French Drain, and Seep L-4, as shown on Figure 3. Cell 1 would receive leachate effluent discharging from the leachate transport pipe, French Drain, and Seep L-4. Cell 2 would receive the effluent from Cell 1 and leachate effluent from Seep A. Each treatment cell would be separated by an earthen berm and lined with native soil and/or a geosynthetic liner system and portions overlain with topsoil. The topsoil areas would be planted and seeded with existing wetland transplants and appropriate seed mixtures overlain by an erosion control blanket or mulch. Flow through the wetland would be by gravity from Cell 1 to Cell 2. Details of these features are shown on Figure 2.

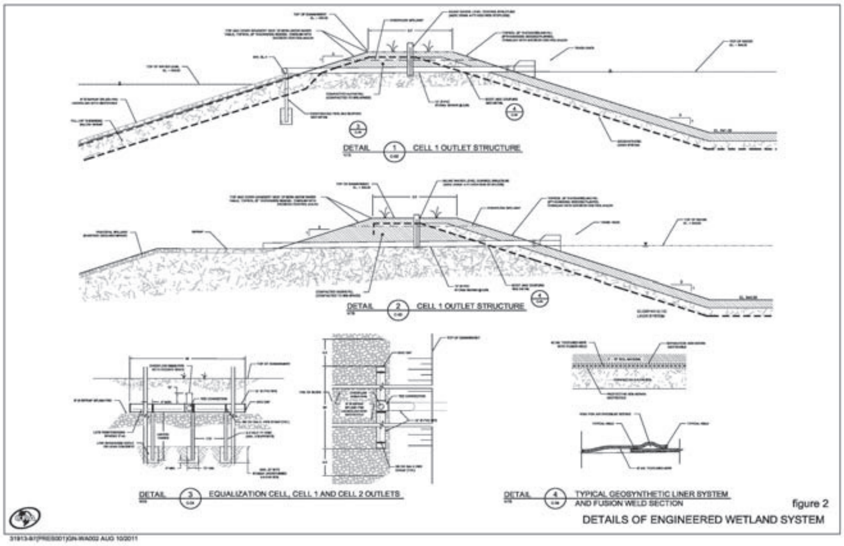


figure 2
DETAILS OF ENGINEERED WETLAND SYSTEM

A key point in the preliminary design approach and consideration was identified as the need to conduct a laboratory bench-scale treatability study to finalize the design of the engineered wetland system. The purpose of the bench-scale treatability study was to determine the effectiveness of the wetland in reducing iron concentrations. It was initially estimated by experience with similar settings that the engineered wetland system would provide about 20 to 40 percent reduction in iron concentrations in the AMD/leachate discharges.

3.0 Bench-Scale Treatability Study

Based on flow rate data collected at the time of sampling, a composite sample was prepared that was representative of leachate entering Cell 1 of the wetland. Flow data are provided in the table below:

Collection Location	*Flow Rate in Gallon per Minute (gpm)*
Leachate Transport Pipe	1.05
Seep A	0.74
Seep L4	9.62
French Drain	10.9

The composite was prepared with water from the leachate transport pipe, Seep L4, and the French Drain in the ratio of (1.0 part leachate transport pipe):(9.3 parts Seep L4): (10.6 parts French drain). The leachate effluent samples and composite sample were analyzed for pH, total suspended solids (TSS), total dissolved solids (TDS), ammonia-nitrogen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), sulfate, and total and dissolved calcium, iron, magnesium, and manganese.

TABLE 1

INITIAL GROUNDWATER CHARACTERIZATION
LABORATORY TREATABILITY STUDY
OHIO SITE

Parameters	*Units*	*LTP*	*SEEP A*	*SEEP L4*	*French Drain*	*Composite*
pH	S.U.	6.03	5.67	5.25	5.70	6.05
Turbidity	NTU	73.2	171	38.5	166	X
Turbidity of Shaken Sample	NTU	579	181	35.5	247	228
TSS	mg/L	140	92.0	33.0	50.0	52.0
TDS	mg/L	2010	4040	4650	1760	1340
Ammonia Nitrogen	mg/L	20.1	10.9	10.1	0.00	0.156
BOD	mg/L	ND (2)	15.8	35.4	ND (2)	ND (2)
COD	mg/L	31.2 B	83.4 B	139 B	24.2 B	66.1 B
Sulfate	mg/L	1280	2650	1450	992	1950
Calcium	µg/L	293000	463000	356000	316000	336000
Iron	µg/L	113000	532000	786000	119000	391000
Magnesium	µg/L	53900	71600	70700	56700	64200
Manganese	µg/L	2860	2140	3120	2070	2600
Dissolved Calcium	µg/L	317000	471000	360000	310000	322000
Dissolved Iron	µg/L	53000	520000	778000	104000	399000
Dissolved Magnesium	µg/L	60100	73700	72600	56500	60800
Dissolved Manganese	µg/L	3130	2180	3160	2030	2490

Note:

B - Method blank contamination.

The results are provided in Table 1. The pH of all of the samples was acidic – between 5.3 and 6.1. The TSS of the water from the leachate transport pipe and Seep A were relatively high (140 and 92 mg/L, respectively). The TSS of Seep L4 and the French Drain were lower (33 and 50 mg/L). The TSS of the composite samples were 52 mg/L.

The TDS of the composite were 1,340 mg/L. Ammonia-nitrogen was highest in the leachate collection pipe (20 mg/L) and lowest in the French Drain (ND [0.25]). BOD and COD were higher in Seeps A and L4 than in the leachate collection pipe or French Drain. Sulfate was greater than 990 mg/L in all of the samples. Total and dissolved calcium, iron, magnesium, and manganese were measured in all of the samples and the composite. In all cases, the total and dissolved values were similar indicating that these metals were predominantly in the dissolved form. Iron was high in all of the samples (composite 400 mg/L).

Different retention times and treatment conditions were tested to determine the minimum retention time for each wetland cell and whether additional treatment such as pH adjustment would improve iron removal rates. The results showed that for the composite (Cell 1), 120 hours of stirring resulted in a reduction of the ferrous (soluble) iron concentration from 260 to 201 mg/L, which was a 23 percent reduction.

The data suggest that the short passive aeration period followed by retention in a wetland would provide approximately 15 to 23 percent reduction in iron concentrations.

The results of air sparging testing suggested that additional treatment would be required in order to achieve significant iron removal from the water. Subsamples of the composite and Seep A water samples were pH adjusted to pH 9 using lime. The samples were allowed to settle for 48 hours. The results of these tests are shown in Table 2. This treatment resulted in a reduction of the ferrous iron concentration in the composite from 260 to 0.11 mg/L (99.9 percent removal) and in Seep A from 258 to 1.16 mg/L (99.6 percent removal). These results suggest that if leachate pH was raised, minimal aeration would be required in order to precipitate significant quantities of iron.

TABLE 2

pH ADJUSTMENT TESTS
LABORATORY TREATABILITY STUDY
OHIO SITE

Parameters	*Units*	*Initials*			
		Composite	*SEEP A*	*Composite*	*SEEP A*
TSS	mg/L	52.0	33.0	1130	2320
Ferrous Iron	mg/L	260	258	0.11	1.16
Amt. Of Lime added	g	0.00	0.00	0.0700	0.0900
pH	S.U.	6.05	5.67	9.56	9.35

In order to determine whether increased aeration could avoid the necessity for pH adjustment, samples were aerated using an air stone for 96 hours. Water samples were tested at their ambient pHs and with their pH raised to pH 9.

These results showed that increased aeration increased iron removal; however, raising the pH again resulted in significantly greater iron precipitation.

Additional tests were performed in order to assess the treatment potential of the wetland, with and without pH adjustment. Solids deposition in the wetland will be continuous; therefore, precipitated iron will not remain in the water column. It is possible that removal of iron will shift the equilibrium between total and dissolved iron and favor the precipitation of additional iron. Therefore, the water samples were aerated for 2 minutes to simulate the passive aeration and then stirred for 120 hours to simulate the wetland retention time. After 72 hours, solids were removed and stirring continued. The testing was performed on samples at the ambient pH and on samples where the pH had been adjusted to pH 9 using lime. The results from this test are shown in Table 3.

TABLE 3

LIMITED AERATION TESTING
LABORATORY TREATABILITY STUDY
OHIO SITE

Parameters	*Units*	*Initials*		*Composite*		*Composite*		*SEEP A*		*SEEP A*	
		Composite	*SEEP A*	*pH 5.05 72 hr.*	*pH 9.32 72 hr.*	*pH 5.05 120 hr.*	*pH 9.32 120 hr.*	*pH 4.34 72 hr.*	*pH 9.15 72 hr.*	*pH 4.34 120 hr.*	*pH 9.15 120 hr.*
Turbidity	NTU	228	181	X	X	3.21	5.17	X	X	0.430	7.01
TSS	mg/L	52.0	33.0	234	555	15.0	12.0	211	658	12.0	13.0
Ferrous Iron	mg/L	260	258	X	X	199	0.12	X	X	229	0.720
Amt. of Lime added	g	0.00	0.00	0.00	0.0700	0.00	0.0700	0.00	0.0700	0.00	0.0700

For the composite (Cell 1) water sample, treatment at ambient pH reduced the ferrous iron from 260 to

199 mg/L (23 percent removal). This removal was similar to that observed in Task 3, therefore, it appeared that removal of the solids did not increase iron removal. Treatment at pH 9.3 reduced the ferrous iron to 0.12 mg/L (99.9 percent removal). This removal was similar to that observed in Task 4, when the pH was adjusted and the sample was allowed to settle, therefore, solids removal did not appear to increase iron removal at a higher pH. The low solids production after the initial solids removal at 72 hours suggested that little additional iron precipitated after the solids removal and that iron precipitation was largely complete after 72 hours.

The results of the treatability study show that an engineered wetland can be used to precipitate iron to effect removal and correspondingly other metals from Site leachate. It is recommended that the leachate pH be raised prior to discharge or more practically during/shortly after discharge to the wetland (i.e., allowing the water flow through or over limestone) to increase removal rates. In the treatability study, the leachate pH was raised to nine to effect significant iron precipitation. It is likely not necessary in the field to raise the leachate pH as high as 9 in order to achieve significant iron removal, and it may be difficult to practically achieve this pH increase in the field. A lower pH such as pH 8 would still result in significant iron precipitation and corresponding reduction in dissolved iron concentration in wetland leachate discharge.

4.0 Final Design Considerations

As a result of the bench-scale treatability study it was considered that the addition of limestone to increase the pH of the AMD/leachate would be a key component not originally considered in the initial design of the engineered wetland.

It is currently estimated that approximately 800 tons of limestone will have to be placed in the engineered wetland to increase the pH to 8, as recommended as a result of the bench-scale treatability study for a period of 20 years.

References

[1] Brodie, G.A., C.R. Brott, H.N. Taylor, and M. Tomaszewski. "Anoxic Limestone Drains to Enhance Performance of Aerobic Acid Damage Treatment Wetlands, Experiences of the Tennessee Valley Authority" (1992) in: Moshiri, G.A (ed.), "Constructed Wetlands for Water Quality Improvement Proceedings of an International Conference", Lewis Publishers, Inc. Chelsea, MI.

[2] Kleinmann, R.L., T.O. Tiernan, S.G. Solch, and B.L. Harris. "A low-cost, low maintenance treatment system for acid mine drainage using Sphagnum moss and limestone" (1983) in: Carpenter, S.B., and R.W. Devore (ed.) "Proclamation of the 1983 Symposium on Surface Mining".

[3] Norton, P. "The Control of Aid Mine Drainage with Wetlands" (1992). Mine Water and the Environment, v.11, No.3, p. 27-34.

[4] Smith, K. "Constructed Wetlands for Treating Acid Mine Drainage" (1997). Restoration and Reclamation Review. University of Minnesota, St. Paul, MN.

[5] United States Environmental Protection Agency (USEPA). "Emergency Technology Summary – Handbook for Constructed Wetlands Receiving Acid Mine Drainage". EPA/540/SR-93/523, 1993.